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2.	Patent application number *(The Patent Office will fill in this part)*	0317387.9 — 25 JUL 2003
3.	Full name, address and postcode of the or of each applicant *(underline all surnames)*	Loughborough University Enterprises Limited Loughborough University, Admin 1 Building, Ashby Road, Loughborough, Leicestershire, LE11 3TU.
	Patents ADP number *(if you know it)*	8440307002
	If the applicant is a corporate body, give the country/state of its incorporation	United Kingdom
4.	Title of the invention	Method and Apparatus for Combining Particulate Material
5.	Name of your agent *(if you have one)*	Swindell & Pearson
	"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*	48 Friar Gate, Derby DE1 1GY
	Patents ADP number *(if you know it)*	00001578001

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Request for substantive examination *(Patents Form 10/77)*	
Any other documents *(please specify)*	

11. I/We request the grant of a patent on the basis of this application

Signature Swindell & Pearson Date 24/07/2003

Swindell & Pearson

12. Name and daytime telephone number of person to contact in the United Kingdom ~~Paul Higgin (01332) 367051~~

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DUPLICATE

Method and Apparatus for Combining Particulate Material

Embodiments of the present invention relate to a method of selectively combining particulate material and/or apparatus for combining particulate material.

Rapid Prototyping is widely used to form prototype components, and a number of methods are currently available for carrying out rapid prototyping. In one method, a computer generated three dimensional model of the component is initially produced using computer assisted drawing (CAD) software. The three dimensional model is then sliced into a number of virtual layers, and a device used to form and combine the layers to create the three dimensional component.

It is known to form the respective layers by combining particulate material using a laser that sinters the particulate material. However, this method can be disadvantageous since the laser must pass over the entire surface of each layer, which can be time consuming. As an alternative, infra-red radiation can be provided on selected portions of a layer of particulate material to combine it. However, the accuracy of the components produced using this method may be unsatisfactory.

According to a first aspect of the present invention, there is provided a method of selectively combining particulate material, comprising the steps of:

(i) providing a layer of particulate material;
(ii) providing variable intensity radiation, over a selected surface portion of the layer, to combine a portion of the material of the layer.

According to a second aspect of the present invention, there is provided apparatus for combining particulate material, the apparatus comprising a controller for enabling the exposure of a surface portion of a

layer of particulate material to radiation, wherein the controller is arranged to control the variation of radiation intensity provided across said surface portion.

Preferred features of the invention are defined in the accompanying claims. The surface portion that receives variable intensity radiation may be a part, and not the whole, of the surface of the layer of particulate material.

The provision of variable intensity radiation over the surface portion requires the existence of multiple areas in which the intensity of radiation is different and greater than zero.

Embodiments of the present invention will now be described by way of example only and with reference to the accompanying drawings, in which:-

Fig. 1 is a diagrammatic illustration of a first embodiment of apparatus for combining particulate material;

Fig. 2 is a diagrammatic plan view of a surface portion of a layer of particulate material;

Fig. 3 is a diagrammatic illustration of a second embodiment of apparatus for combining particulate material;

Fig. 4 is a diagrammatic view of a third embodiment of apparatus for combining particulate material;

Fig. 5a is a further diagrammatic plan view of a surface portion of a layer of particulate material;

Fig. 5b is a side view of the layer of particulate material of Fig. 5a;

Fig. 6 is a diagrammatic schematic view of apparatus for combining particulate material being used to form a three dimensional object; and

Fig. 7 is a diagrammatic view of the apparatus of Fig. 1 being used to combine different types of particulate material.

Referring to the drawings, there is shown generally apparatus for combining particulate material, for example plastics material by sintering, the apparatus comprising a controller C for enabling the exposure of a surface portion of a layer 10 of particulate material to radiation, for example infra-red radiation provided by a radiation source 12, the controller C being arranged to control the variation of radiation intensity provided across the surface portion.

In more detail, Fig. 1 illustrates a first embodiment of apparatus for sintering particulate material in which an obscurer 14 (i.e. a mask) is provided for selectively obscuring the radiation provided by the source 12 on the surface portion of the layer 10. The obscurer 14 comprises a radiation transmissive substrate 16, such as a glass plate, which carries a varying amount of radiation reflective material 18, such as aluminium oxide. The amount and pattern of material 18 deposited on the substrate may be varied to selectively vary the intensity of radiation incident on the surface portion of the layer 10, as will be described hereinafter.

Referring also to Fig. 2, the surface portion of the layer 10 is logically divided by the obscurer 14 into a number of areas including a combination portion 20, which is to be exposed to radiation to combine the particulate material, and a non-combination portion 22 which is to be shielded, or at least substantially shielded, from radiation to prevent combination of the particulate material by sintering. Full shielding of the non-combination portion 22 is not essential, provided that the intensity of radiation transmitted to the non-combination portion 22 is such that the particulate material is not heated to its sintering temperature. In some circumstances, transmission of low intensity radiation onto the non-combination portion 22 to heat the material can be desirable and can result in improved accuracy of the finished component. This is because heating material in the non-combination portion 22 reduces the thermal gradient between the material in the combination portion 20 and the non-combination portion 22.

The combination portion 20 is logically divided by the obscurer 14 into a central portion 24 and an edge portion 26, and reflective material 18 is deposited onto the substrate 16 such that a greater density of the material 18 is provided on the central portion 24 than on the edge portion 26 where no reflective material 18 may be provided. Consequently, the intensity of radiation provided across the surface of the combination portion 20 increases from a minimum value at the central portion 24 to a maximum value at the edge portion 26 where the surface of the layer 10 of particulate material is fully exposed to radiation provided by the radiation source 12.

The layer of reflective material is schematically illustrated in Fig. 1. The variation of thickness of the layer in the figure does not illustrate a variation of thickness of the layer in practice but illustrates a variation in the density of the material. Where the layer is thick in the figure, in practice it will have a high density.

Although the combination portion 20 has been shown to have only one edge portion 26 such that the central portion 24 is located at the centre of the combination portion 20, it should be appreciated that the combination portion 20 may for example be of annular configuration such that the central portion 24 is bounded on two sides by edge portions 26. Moreover, it is not essential ~~that the central portion 24 is located at the centre of the surface portion of the~~ layer 10 of particulate material.

The controller C is arranged to control a motor 28 for moving the obscurer 16 from an obscuring position in which it overlies the layer 10, as shown in Fig. 1, to a non-obscuring position in which it does not overly the layer 10. The controller C is also arranged to control a deposition device, such as a printing head 30, for depositing the reflective material 18 onto the substrate 16. The controller C controls the amount of material 18 deposited by the head 30 onto each part of the substrate 16. In the embodiment shown in Fig. 1, the head 30 remains stationary and deposits reflective material 18 onto the substrate 16 as the motor 28 moves the substrate 16 past the head 30. In

an alternative embodiment (not shown), the substrate 16 may remain stationary, overlying the layer 10, and the motor 28 may move the printing head 30 over the substrate 16 to deposit reflective material 18 thereon.

In the illustrated embodiment, the reflective material 18 is contemporaneously printed onto the substrate 16 during operation of the apparatus. The amount of material 18 printed onto the substrate 16 by the head 30 may be varied by the controller C according to the surface temperature of the layer 10. The surface temperature of the layer 10 may be measured by a temperature measuring device, such as, for example, a pyrometer P or a thermal imaging camera, and surface temperature measurements are communicated in real time to the controller C. A wiping arrangement (not shown) may be provided for removing reflective material 18 from the substrate 16, so that it can be re-used. Different amounts of material 18 can be deposited onto the substrate 16, in dependence on the desired radiation intensity profile at the substrate surface.

Alternatively, the reflective material 18 may be pre-printed onto the substrate 16 prior to operation of the apparatus and the same pre-printed substrate 16, or a number of pre-printed substrates 16, may be used, one for each layer 10 of particulate material. In this case, measurement of the surface temperature using pyrometer P may not be needed.

Fig. 3 illustrates a second embodiment of apparatus for combining particulate material, in which corresponding elements are given corresponding reference numerals. The apparatus of Fig. 3 is similar to that shown in Fig. 1, except that instead of the reflective material 18 being deposited onto a substrate 16, the reflective material 18 is deposited, using the printing head 30, directly onto the surface portion of the layer 10 of particulate material.

In the apparatus of this embodiment, the printing head 30 is again controlled by the controller C which controls both the movement of the head 30 across the surface of the layer 10 and the rate of deposition of reflective material 18 onto the layer 10. Again, real time measurement of the surface

temperature of the layer 10 may be carried out using a temperature measurement device, for example, a pyrometer P or thermal imaging camera, the temperature measurement being used by the controller C to determine the amount of reflective material 18 to be printed by the head 30 onto the surface portion of the layer 10.

The layer of reflective material is schematically illustrated in Fig. 3. The variation of thickness of the layer in the figure does not illustrate a variation of thickness of the layer in practice but illustrates a variation in the density of the material. Where the layer is thick in the figure, in practice it will have a high density.

Fig. 4 illustrates a third embodiment of apparatus for combining particulate material which is similar to the first and second embodiments and in which corresponding elements are given corresponding reference numerals. In this embodiment, the controller C is arranged to selectively redirect the radiation provided by the source 12 and thereby vary the radiation intensity incident across the surface portion of the layer 10. Selective redirection of the radiation is achieved by controlling, using the controller C, a plurality of mirrors 34 which form a Digital Mirror Device (DMD) 36. Each mirror 34 is adjustable by the controller to an operative position, in which radiation is fully redirected onto the surface portion of the layer 10, or to an ~~inoperative position in which radiation is fully redirected away from the surface~~ portion. By providing an array of mirrors 34, the surface portion of the layer 10 can be effectively divided into an array of segments, as discussed hereinafter, and the intensity of the radiation incident on each segment can be varied, according to a bitmap image, by selectively varying the frequencies at which individual mirrors 34 are moved between the operative and inoperative positions.

Use of a temperature measurement device, such as a pyrometer P,, although optional is particularly advantageous with the apparatus of this embodiment as the position of each mirror 34 can be instantaneously

controlled, in real time, by the controller C in response to instantaneous temperature variations across the surface portion of the layer 10.

Referring now to Figs. 5a and 5b, the apparatus according to the invention allows the surface portion of the layer 10 of particulate material to be logically divided into an array of segments 32. The controller can control the intensity of radiation incident on each segment 32 independently and a bitmap image can be used to specify the intensity of radiation that should be incident on the surface portion. The greyscale of each segment 32 of the bitmap image is individually adjustable, and in the case of the first and second embodiments of the apparatus, the amount of reflective material 18 deposited onto each segment of the substrate 16 or surface portion of the layer 10 is individually adjustable, according to the bitmap image, to provide any desired radiation intensity profile over the surface portion of the layer 10. When the apparatus of the third embodiment is employed, the mirrors 34 are adjusted to vary the intensity of radiation incident on each segment 32 of the array.

In the arrangement shown in Figs. 5a and 5b, a first density of reflective material 18 has been deposited by printing head 30 onto the segments 32 defining the central portion 24 of the combination portion 20. Accordingly, a first intensity of radiation, which is less than the maximum intensity, is incident on the surface portion of the layer 10 located beneath these segments 32. The first intensity of radiation is sufficiently high to raise the temperature of the particulate material to cause it to combine.

No reflective material 18 has been provided on the segments 32 which define the edge portion 26 of the combination portion 20, thereby allowing a maximum intensity of radiation to reach the surface portion of the layer 10 located beneath these segments 32. The maximum intensity of radiation causes the particulate material located beneath the segments 32 defining the edge portion 26 to combine more quickly than particulate material in the central portion 24.

A second density of reflective material 18, which is greater than the first density, is deposited by printing head 30 onto the segments 32 defining the non-combination portion 22. A sufficient density of material 18 may be provided to prevent transmission of any radiation to the surface portion of the layer 10 located beneath these segments 32. Consequently, the particulate material located beneath these segments 32 does not combine.

Whilst variation of the radiation intensity on each individual segment 32 has been described with respect to the second embodiment of the apparatus, it is to be understood that the same effect can be achieved using apparatus according to the first embodiment, in which reflective material 18 is printed onto a substrate 16, or according to the third embodiment, in which mirrors 34 are used to vary the intensity of radiation incident on each segment 32.

The layer of reflective material is schematically illustrated in Fig. 5b. The variation of thickness of the layer in the figure does not illustrate a variation of thickness of the layer in practice but illustrates a variation in the density of the material. Where the layer is thick in the figure, in practice it will have a high density.

Referring now to Fig. 6, there is shown a diagrammatic illustration of the apparatus of Fig. 3 being used to form a three dimensional object 38. Again, elements of the apparatus which have been referred to above are given corresponding reference numerals.

The apparatus is used to form a three dimensional object 38 by combining a plurality of layers 10a to 10e of particulate material. A supply of particulate material, for example Nylon powder, is provided in a supply tank 40 and the controller C is arranged to control a motor M which can move particulate material from the tank 40 into a building device 42, which includes a vertically movable platform 44. Movement of the platform 44 is controlled by the controller C, such that the platform 44 is moved vertically downwards in discrete steps after each layer 10 has been formed.

Initially, with the platform 44 in an uppermost position, the controller C actuates the motor M to provide a first layer 10a of particulate material on the platform 44. The controller C then actuates the printing head 30 to deposit a desired pattern of reflective material 18 onto the surface portion of the layer 10 of material. Alternatively, the reflective material 18 may be deposited by the printing head 30 onto a substrate 16, as previously discussed, or the intensity incident at the surface may be controlled using digital mirrors.

The controller C then activates the radiation source 12 to provide radiation over a selected surface portion of the layer 10, as defined by the reflective material 18. As shown in Fig. 6, radiation is provided with varying intensity across the combination portion 20 and the material in this portion is combined. The reflective material 18 prevents, or at least substantially prevents, transmission of radiation to the surface portion of the material in the non-combination portion 22 where the material is not combined and remains in particulate form. The varying amount of reflective material 18 thus provides for variable intensity radiation across the combination portion 20 of the layer 10.

After combination of the material in the combination portion 20 of the first layer 10a has been carried out, the controller C deactivates the radiation source 12 and lowers the platform 44 by a distance approximately equivalent to the desired layer thickness. The controller C then actuates the motor M to provide a second layer 10b of particulate material overlying the first layer 10a including a previously combined portion of material. The controller C then actuates the printing head 30 to deposit reflective material 18 onto the surface portion of the second layer 10b. The amount and pattern of reflective material 18 deposited onto the surface portion of the second layer 10b may be the same as that provided on the first layer 10a, or may be different, for example in response to design or surface temperature measurements carried out using the pyrometer P. The controller C then activates the radiation source 12 to provide radiation across the surface portion of the second layer 10b, the reflective material 18 providing for variable intensity radiation across the surface portion. The material in the combination portion 20 of the second layer

10b is thus caused to combine, and also to combine with the previously combined portion of material in the first layer 10a. The adjacent layers 10a, 10b are thus combined to form part of a coherent object 38.

The controller C continues to operate in this manner to provide further layers 10c to 10e of particulate material and combine them, until formation of the object 38 has been completed. Once the coherent object 38 has been formed, the platform 44 is raised by the controller C to eject the combined object 38 and any remaining uncombined particulate material surrounding the object 38 from the device 42.

Fig. 7 illustrates use of the apparatus of Fig. 1 to combine different particulate materials P1 and P2 which are located adjacent to each other in a layer 10. By way of illustration, the material P1, for example copper, may have a lower melting point than the material P2, for example steel, and may therefore combine by sintering at a lower temperature. The concentration of material P2 decreases from right to left across a transition gradient region 19. across. The concentration of material P1 decreases from left to right across the transition gradient region 19.

In order to ensure optimum material characteristics and minimise thermal stresses over the gradient region 19 between the materials P1 and P2, the substrate 16 may be provided with a high density of reflective material 18 on the portion overlying the material P1 of the layer 10, a low density of reflective material on the portion overlying the material P2 and a density of reflective material over the gradient region 19 that decreases from left to right in the figure. By varying radiation intensity in this way, the materials P1 and P2 are heated to different temperatures using a fixed intensity radiation source 12 and are simultaneously combined to form a coherent layer.

The layer of reflective material 18 is schematically illustrated in Fig. 7. The variation of thickness of the layer in the figure does not illustrate a variation of thickness of the layer in practice but illustrates a variation in the

density of the material. Where the layer is thick in the figure, in practice it will have a high density

Whilst the first embodiment of the apparatus has been described for use in combining the dissimilar particulate materials P1 and P2, it will be readily appreciated that the second embodiment of the apparatus in which reflective material 18 is printed directly onto the surface portion of the layer 10, or the third embodiment of the apparatus which uses mirrors 34 to selectively redirect radiation, could alternatively be used.

In any of the above described embodiments, it may be desirable to add radiation absorbing material to the particulate material to increase the absorption of radiation. For example, a material such as carbon black may be used for this purpose.

Although embodiments of the invention have been described in the preceding paragraphs with reference to various examples, it should be appreciated the various modifications to the examples given may be made without departing from the scope of the present invention, as claimed. For example, although in the embodiments of Figs 1, 2, 3, 5a, 5b and6, the layer 18 has been described as radiation reflective material, it may alternatively be a radiation absorbent material. Although the use of infra-red radiation is described radiation other than infra-red may be used, provided that it is able to elevate the particulate material to a temperature at which it combines by sintering. The source of radiation may be of any suitable type, for example, LEDs or a scanning laser. The particulate material that is combined by the above described embodiments may be any suitable material, such as a metal, ceramic etc. A device other than a motor M may be used to move particulate material from the supply tank 40 to the combination device 42. The combination device 42 may be of a different configuration to that shown. Any number of different types of particulate material may be provided in a layer 10. Alternatively, different types of particulate material may be provided in adjacent layers. Reflective material 18 may be deposited onto a lower surface of the substrate 16 rather than an upper surface, as illustrated. Different

materials may be used for the reflective material 18 and the substrate 16. The digital mirror device described in relation to Fig. 4 could be replaced by a series of diffractive optics, one for each layer.

Whilst endeavouring in the foregoing specification to draw attention to those features of the invention believed to be of particular importance, it should be understood that the Applicant claims protection in respect of any patentable feature or combination of features hereinbefore referred to and/or shown in the drawings, whether or not particular emphasis has been placed thereon.

Claims

1. A method of selectively combining particulate material, comprising the steps of:

   (i) providing a layer of particulate material; and
   (ii) providing variable intensity radiation, over a selected surface portion of the layer, to combine a portion of the material of the layer.

2. A method according to claim 1, wherein step (ii) comprises providing a first intensity of radiation on a first area of the selected portion and a second different intensity of radiation on a second area of the selected portion, contiguous with the first area.

3. A method according to claim 2, wherein step (ii) comprises providing a third different intensity of radiation on a third area of the selected portion, contiguous with the second area.

4. A method according to claim 2 or claim 3, wherein step (i) comprises providing a first particulate material in the first area and a second different particulate material in the second area of the layer.

5. A method according to claim 1, wherein step (ii) comprises providing radiation on a combination area in which particulate material is to be combined, the combination area including a centre portion and an edge portion, the intensity of the radiation being greater at the edge portion than at the centre portion.

6. A method according to claim 5, wherein the intensity of the radiation increases from a minimum intensity value at the centre portion to a maximum intensity value at the edge portion.

7. A method according to claim 5 or claim 6, wherein step (ii) comprises providing radiation on a non-combination area contiguous with, and external to, the combination area, the intensity of the radiation provided on the non-combination area being less than the intensity of the radiation provided on the edge portion of the combination area.

8. A method according to claim 7, wherein the intensity of the radiation provided on the non-combination area is less than the intensity of the radiation provided on the centre portion of the combination area.

9. A method according to any of the preceding claims, wherein step (ii) comprises logically dividing the surface area of the selected portion into an array of segments, and providing a different intensity of radiation on different segments in the array.

10. A method according to claim 9, wherein step (ii) comprises creating a bitmap image that divides the surface area into a plurality of segments.

11. A method according to any of the preceding claims, wherein step (ii) comprises selectively obscuring the provided radiation to vary its intensity at the surface of the layer of particulate material.

~~12. A method according to any one of claims 1 to 10, further comprising~~ providing varying amounts of radiation reflective material over the selected surface portion of the layer to vary the intensity of radiation over the selected surface portion of the layer.

13. A method according to any one of claims 1 to 10, further comprising providing varying amounts of radiation absorbent material over the selected surface portion of the layer to vary the intensity of radiation over the selected surface portion of the layer.

14. A method according to any of claims 1 to 10, wherein step (ii) comprises selectively redirecting the provided radiation to vary its intensity at the surface of the layer of particulate material.

15. A method according to any of the preceding claims, comprising the steps of:

(iii) providing a further layer of particulate material overlying a prior layer of particulate material including a previously combined portion of material;

(iv) repeating step (ii) to combine a further portion of the material within the overlying further layer and to combine said further portion with the previously combined portion of material in the prior layer.

16. A method according to claim 15, wherein steps (iii) and (iv) are successively repeated to form a three dimensional object.

17. Apparatus for combining particulate material, the apparatus comprising a controller for enabling the exposure of a surface portion of a layer of particulate material to radiation, wherein the controller is arranged to control the variation of radiation intensity provided across said surface portion.

18. Apparatus according to claim 17, wherein the controller is responsive to temperature variation across the surface portion and is arranged to control the variation of radiation intensity in response to the temperature variation.

19. Apparatus according to claim 17 or claim 18, wherein the controller is arranged for selectively obscuring the radiation to vary the radiation intensity across the surface portion.

20. Apparatus according to any of claims 17 to 19, wherein the apparatus comprises an obscurer for selectively obscuring the radiation provided on the

surface portion and the controller is arranged to control the obscurer for varying the radiation intensity across the surface portion.

21. Apparatus according to claim 20, wherein the obscurer comprises a radiation transmissive substrate carrying reflective material and overlying the surface portion and the controller is arranged to control deposition of the reflective material onto the substrate.

22. Apparatus according claim 17 or 18, wherein the controller is arranged to control the deposition of varying amounts of radiation absorbent material directly onto the surface portion of the layer of particulate material.

23. Apparatus according to claim 17 or claim 18, wherein the controller is arranged to control the deposition of varying amounts of reflective material directly onto the surface portion of the layer of particulate material.

24. Apparatus according to claim 17 or claim 18, wherein the controller is arranged for selectively redirecting the radiation to vary the radiation intensity across the surface portion.

25. Apparatus according to claim 24, wherein the controller is arranged to control a plurality of mirrors to selectively redirect the radiation.

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26. A method of selectively combining particulate material substantially as hereinbefore described with reference to the accompanying drawings.

27. A method of selectively combining particulate material, comprising the steps of:

(i) providing a layer of particulate material;

(ii) providing varying amounts of radiation absorbent material over a selected surface portion of the layer of particulate material; and

(iii) providing radiation to combine a portion of the material of at least the layer of particulate material.

28. Apparatus for combining particulate material, the apparatus comprising a controller for enabling the exposure of a surface portion of a layer of particulate material to radiation, wherein the controller is arranged to control the variation of radiation intensity provided across said surface portion by controlling the deposition of varying amounts of radiation absorbent material over the layer of particulate material.

29. Apparatus for combining particulate material substantially as hereinbefore described with reference to the accompanying drawings.

30. Any novel subject matter or combination including novel subject matter disclosed herein, whether or not within the scope of or relating to the same invention as any of the preceding claims.

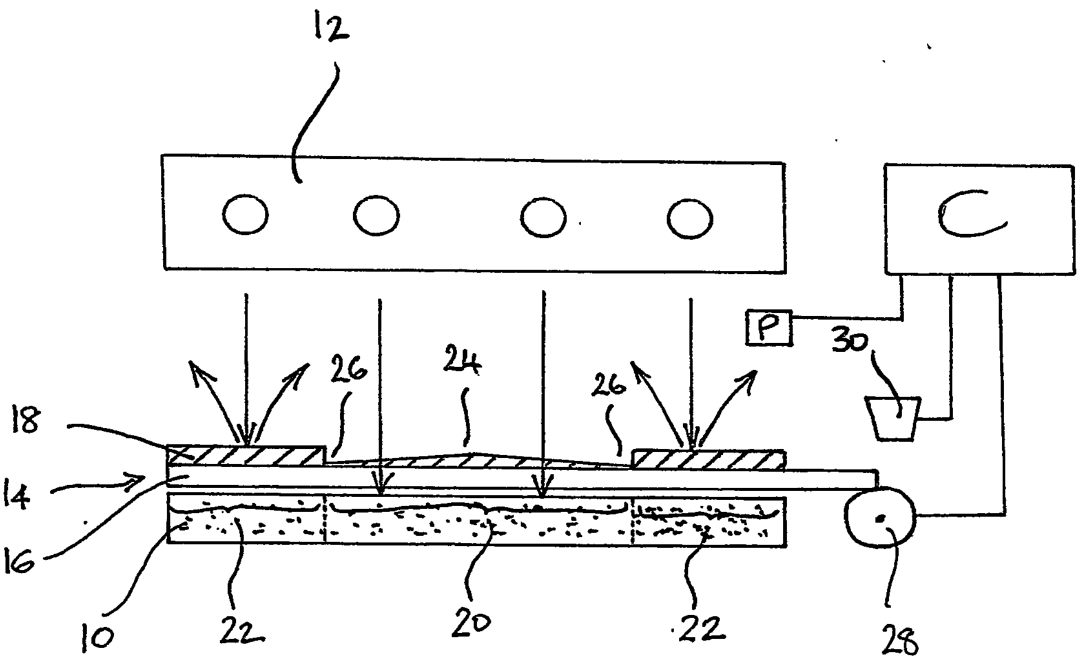

FIG. 1

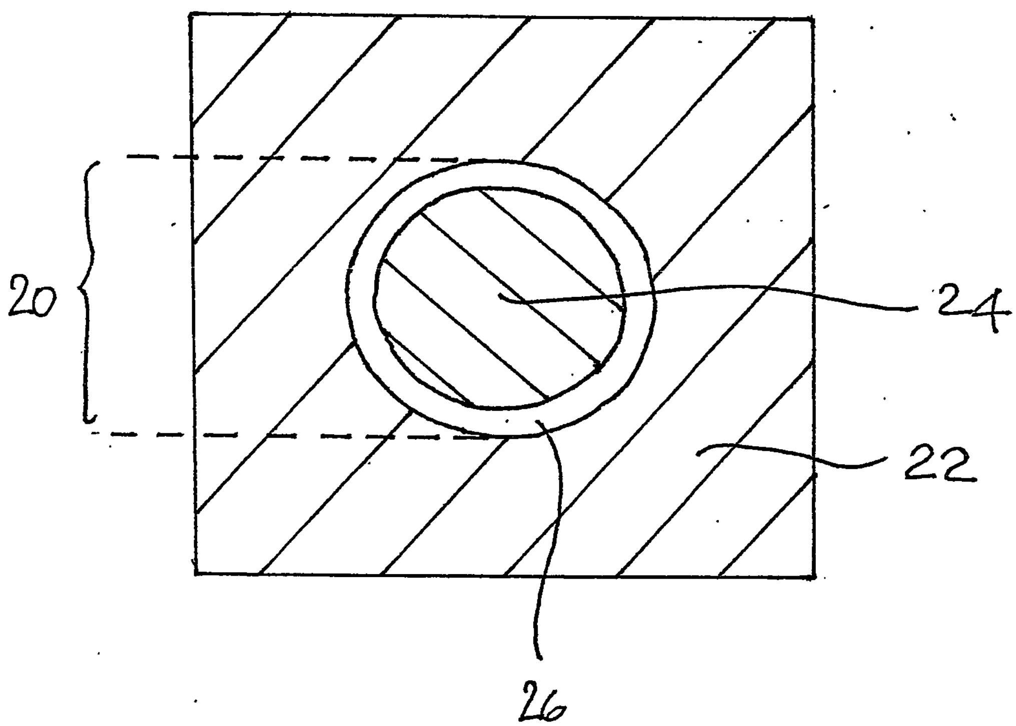

FIG. 2

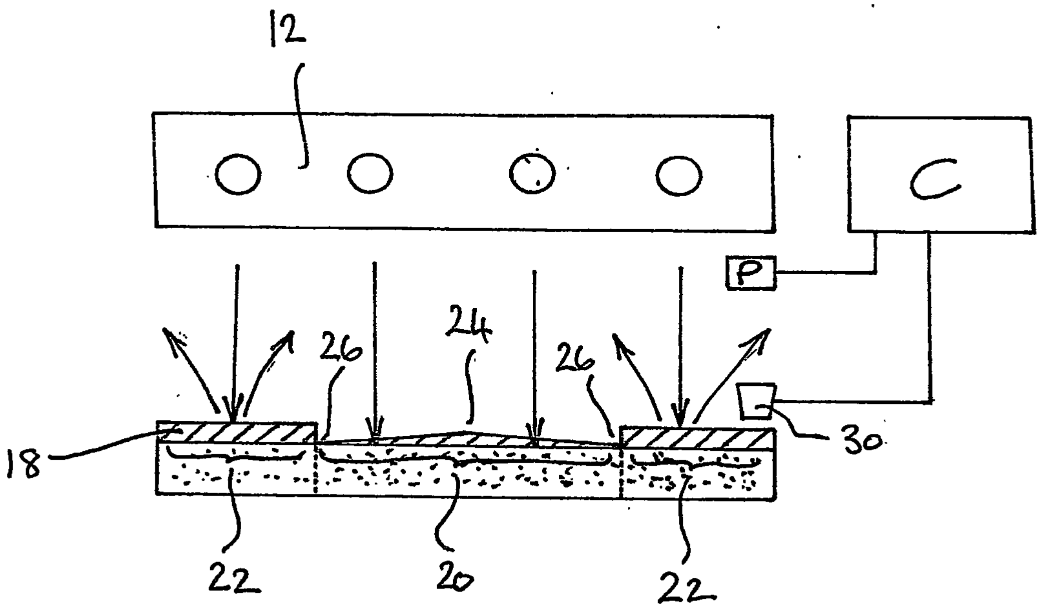

FIG. 3

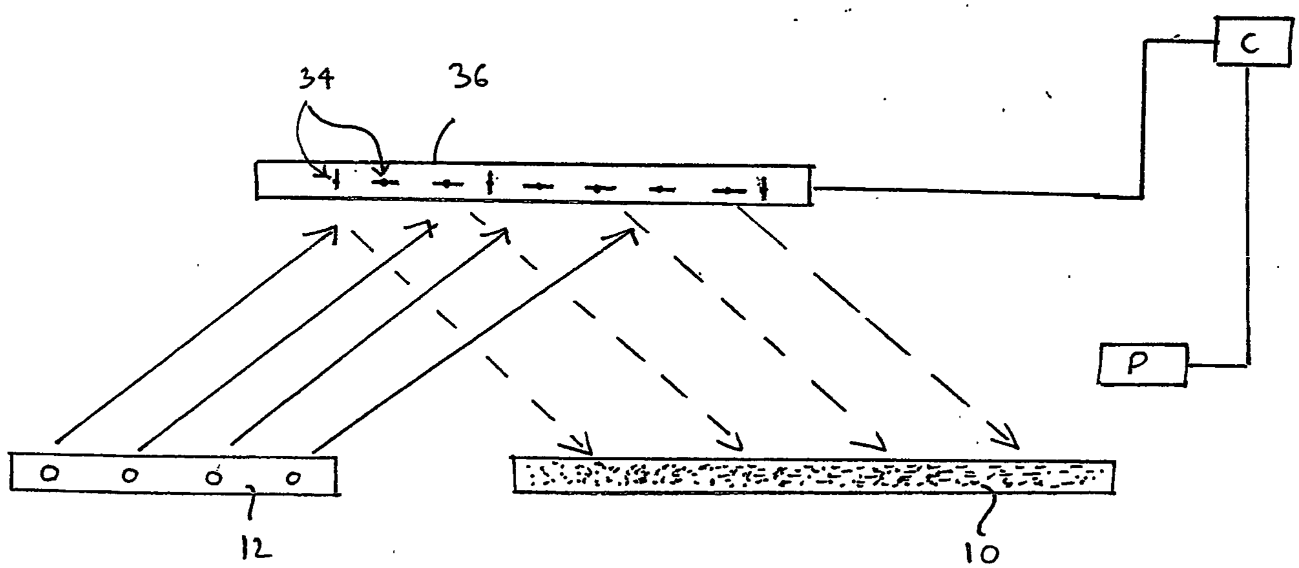

Fig. 4

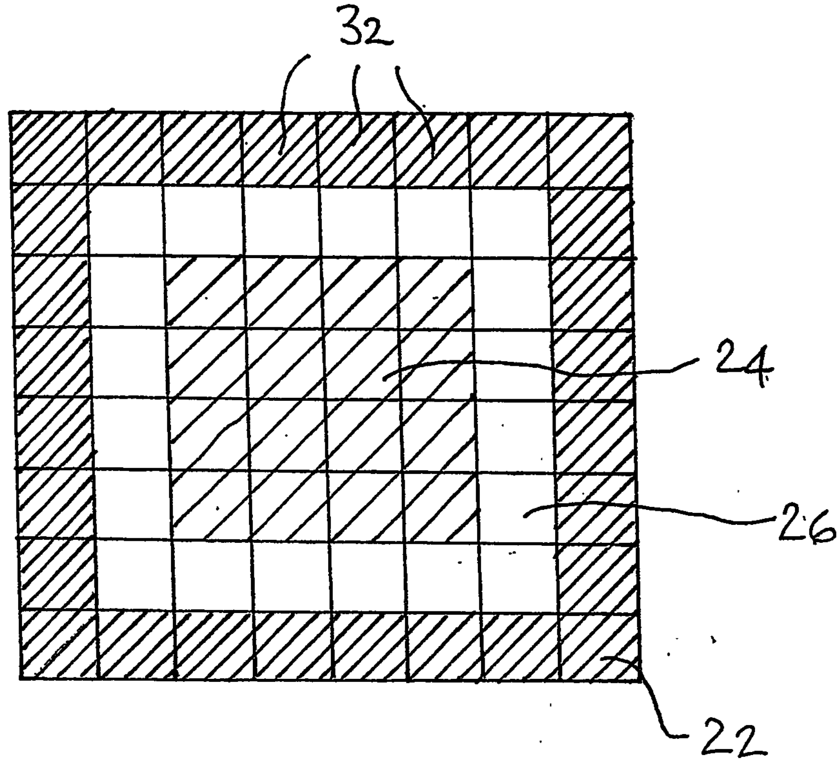

FIG. 5a

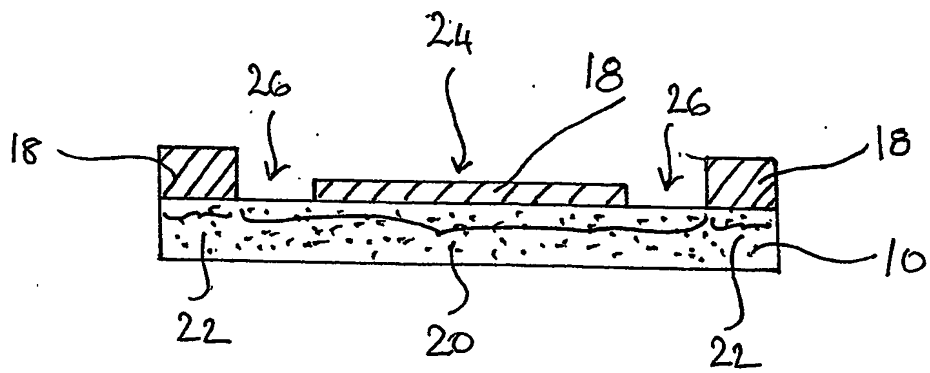

FIG. 5b

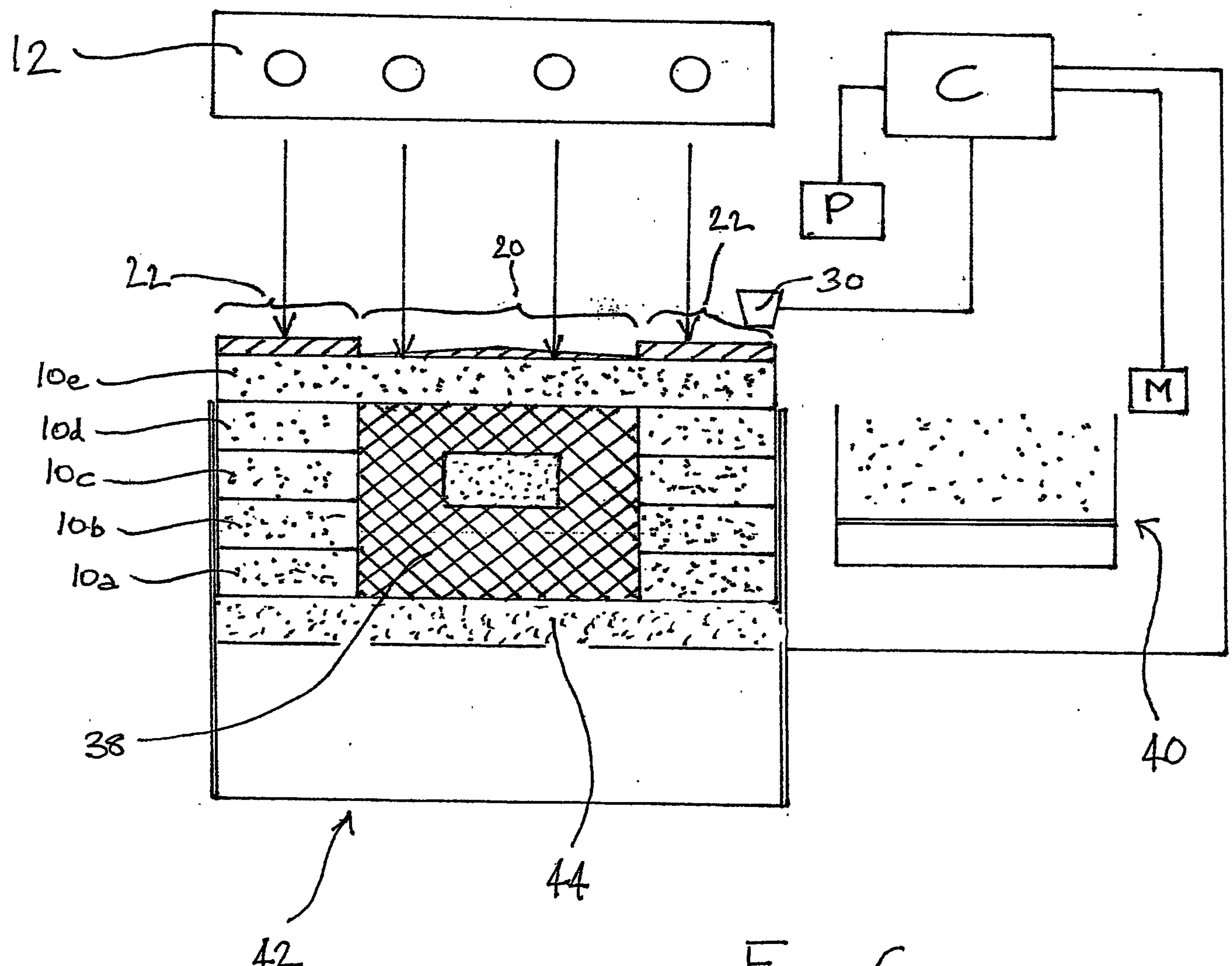

FIG. 6

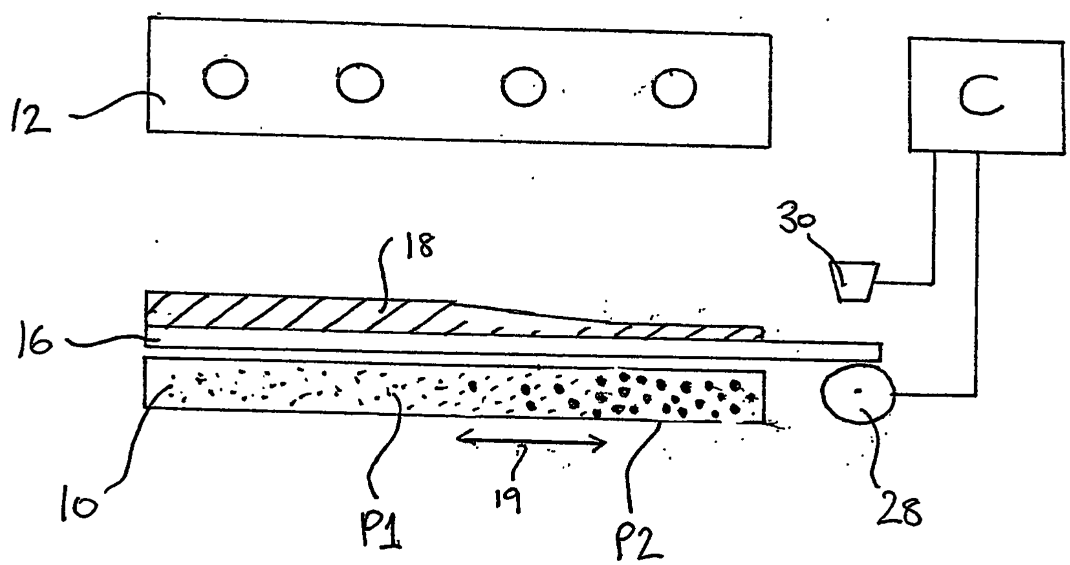

FIG. 7